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# Low Cost, Low Power, Passive Muon Telescope For Interrogating Martian Sub-Surface

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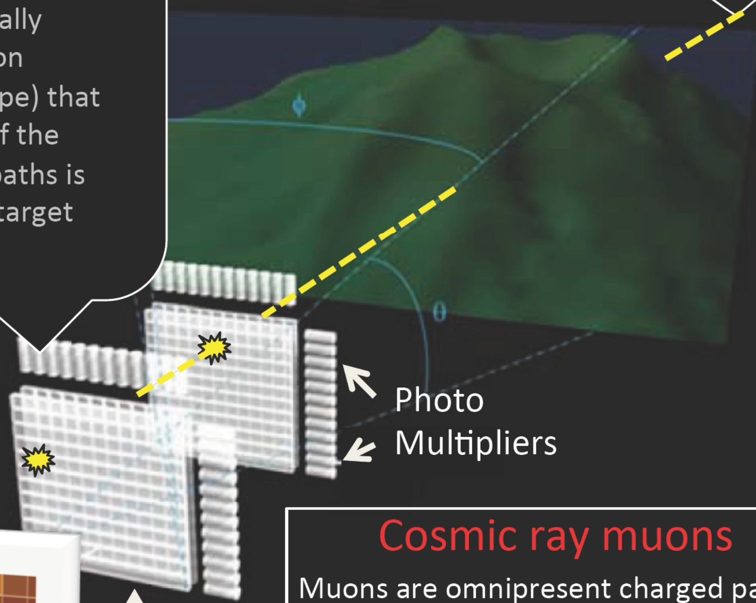
# How Does Muon Tomography Work?

Horizontal Cosmic ray muons penetrate target on one side

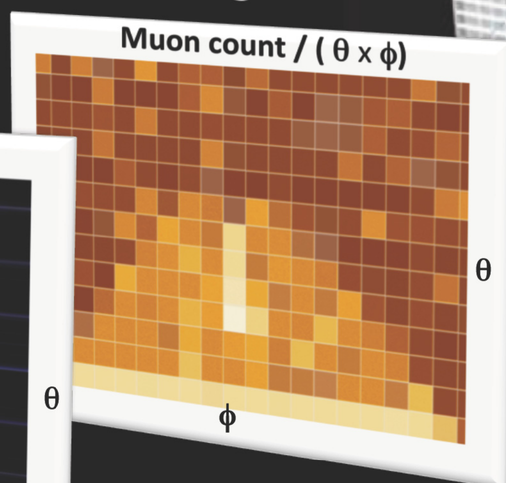
Detector comprised of two arrays of orthogonally oriented scintillation counters (hodoscope) that enables tracking of the incoming muons' paths is placed to observe target from a distance.

$$E = (X - Lr)^T W (X - Lr)$$

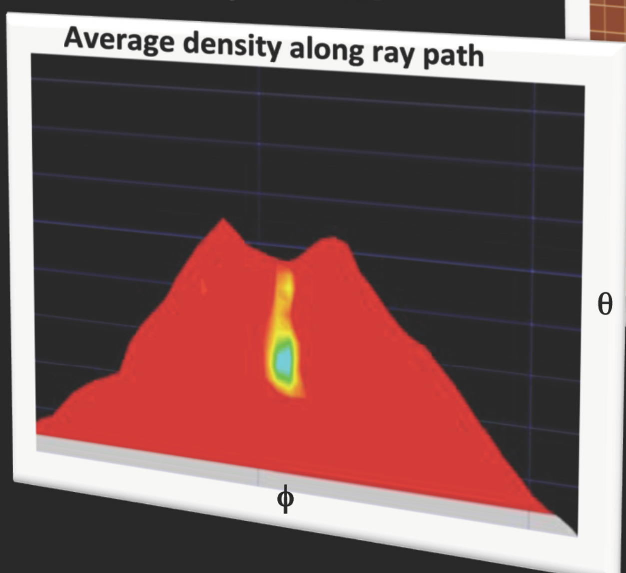
A density profile of the target is calculated by convolving muon counts per pixel (muogram) with knowledge of target area topography and nominal material properties.




## Muogram

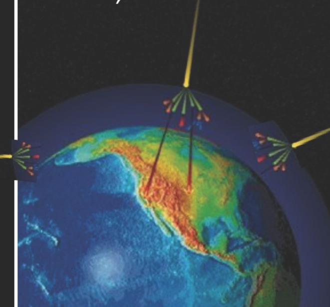



## Density Profile




## Cosmic ray muons

Muons are omnipresent charged particles. On Earth and on Mars they are generated from the decay of secondary particles created when galactic cosmic rays interact with matter in the planet's atmosphere. Muons do not interact strongly with matter, so those with high energy and relativistic momentum can travel long distances before decaying, penetrating deep into rock.



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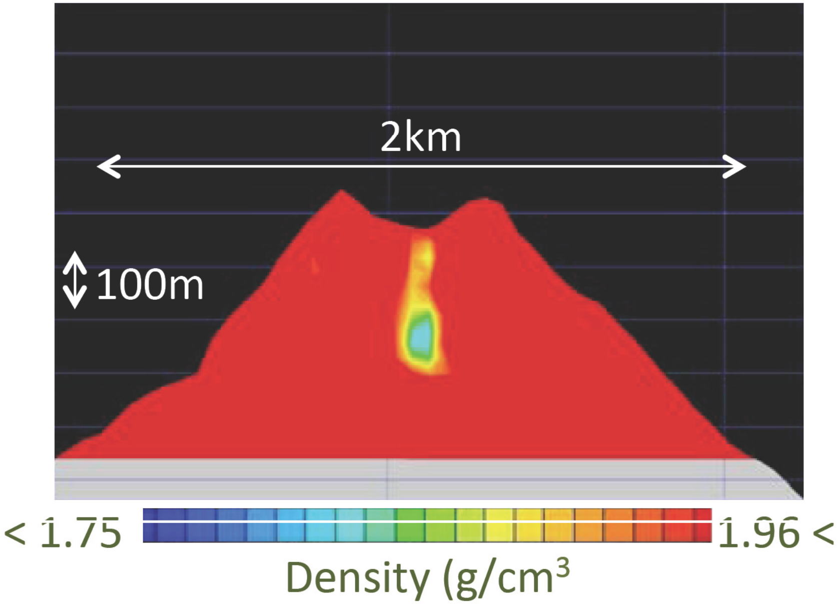
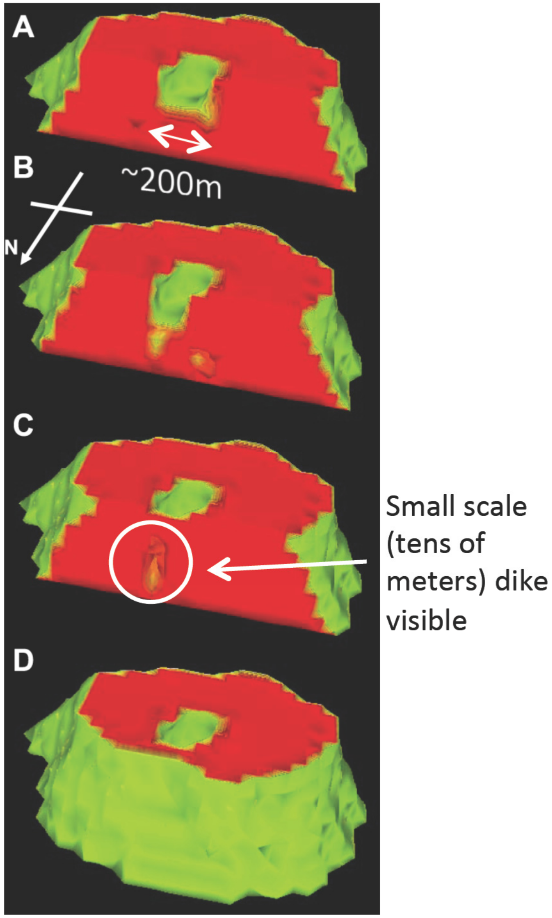
# Recent volcano studies using cosmic ray muon tomography

## Small density variations detected with a single detector (Satsuma-Iwojima Volcano)

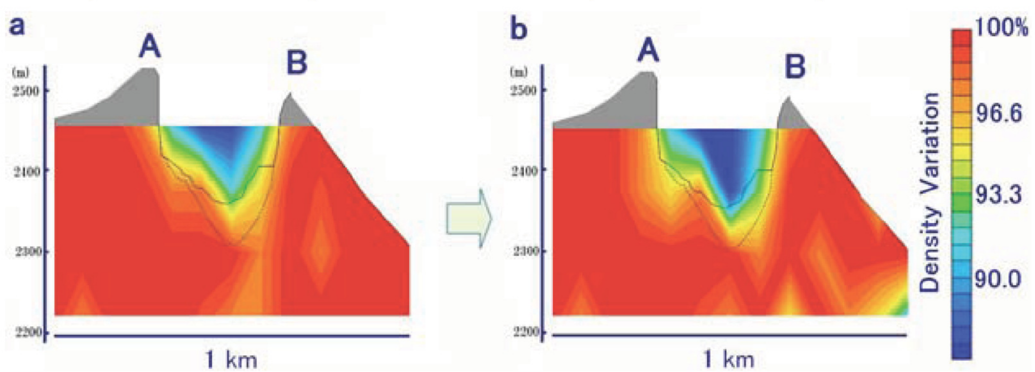



## Two detectors yield a 3D tomography of the density anomaly (Mt. Asama)




## Temporal density variations detected (Mt. Asama)

Jan. 6, 2009 – Feb. 2, 2009 Feb. 2, 2009 – Mar. 5, 2009




[*Tanaka et al.*, 2008, 2009, 2010]

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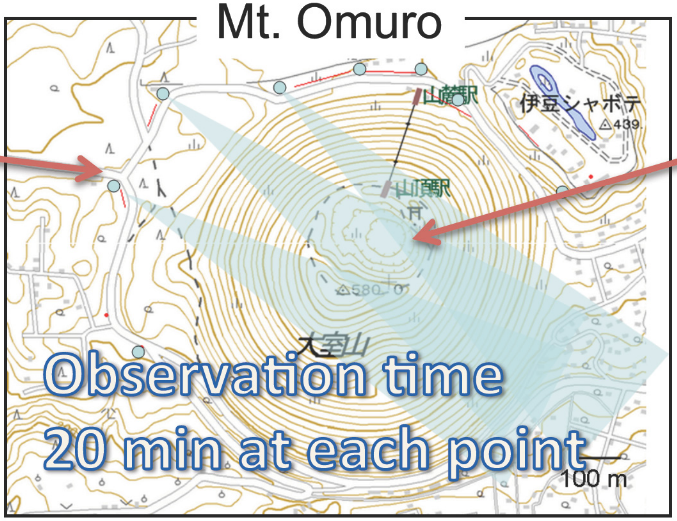
# Recent Field Demo of a Mobile Low-Power, Lightweight Muon Detector

***A MSL-sized mobile muon detector roves around Mt Omuro Imaging the interior in 6 hours***

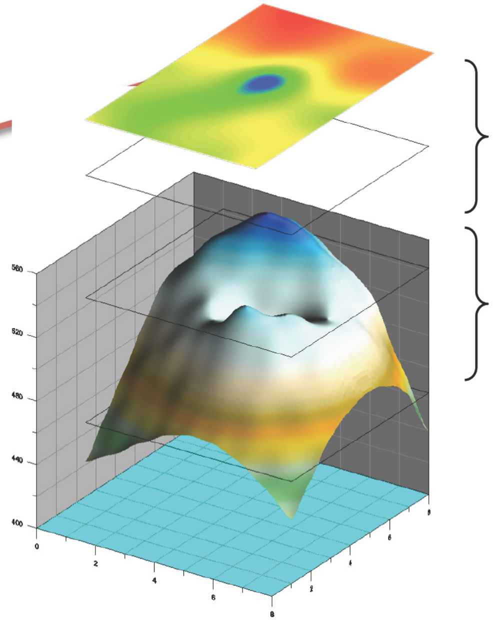
Mobile Muon Detector

Battery–operated electronics

Mt. Omuro




Total observation time
20 x 18 = 360 min



**Exterior shape information is not necessary.**
**Real-time changing target is possible, e.g., growing lava dome**

[Recent results from H. Tanaka et. al. 2011-2012]

# Mars Surface Exploration

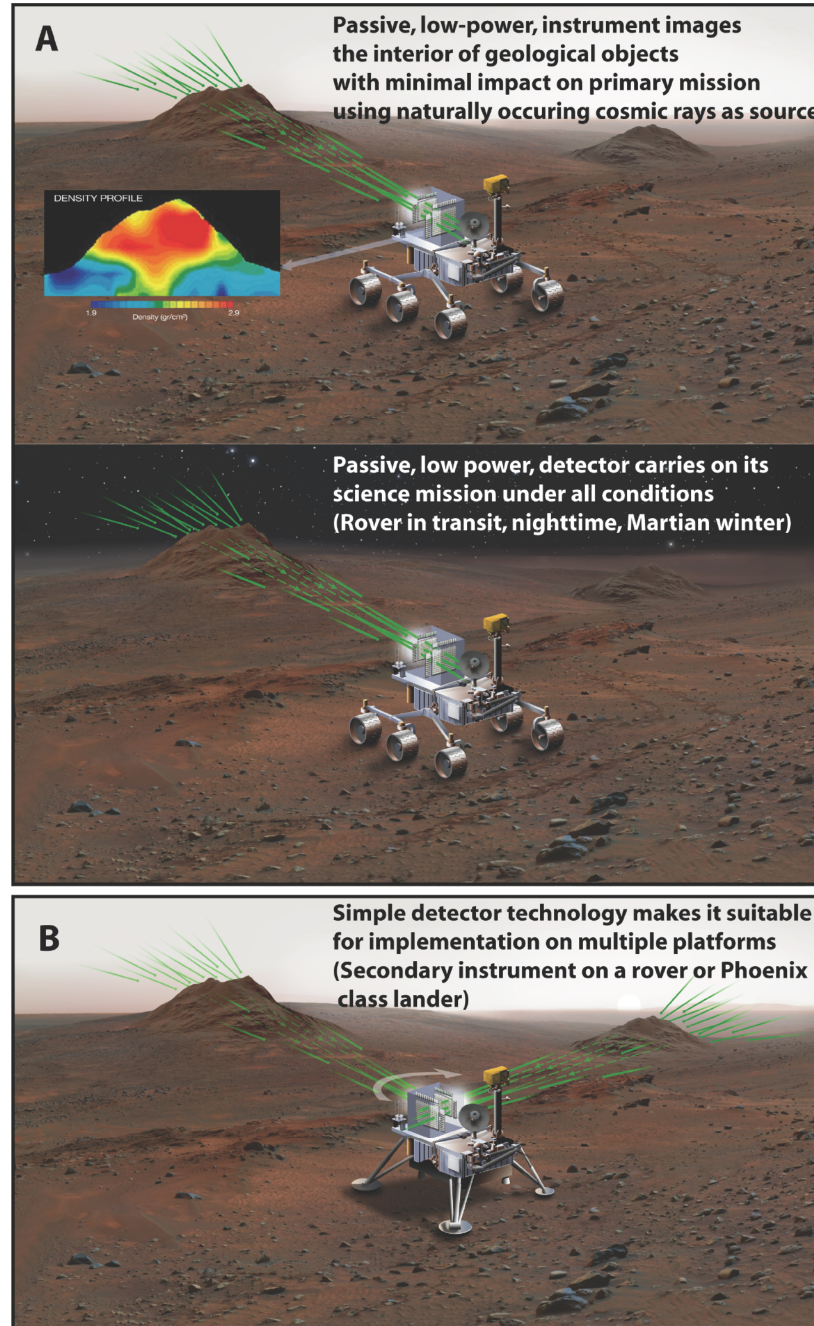
Although the Martian atmosphere is thinner than Earth's, model calculations indicate that horizontal muon flux on Mars' surface will be ~2 times *higher* !

Power usage is ~1 watt, a small fraction of even MER A and B capabilities.

Trade space between detector size and integration times makes it suitable on multiple platforms and numerous targets.

It is a low power, passive detector with high spatial resolution using nature's cosmic rays as a source. Can used as a primary or secondary instrument.

Ideal for deep penetration (1-3 Km) of geological structures or for quick interior views from a rover on the go.



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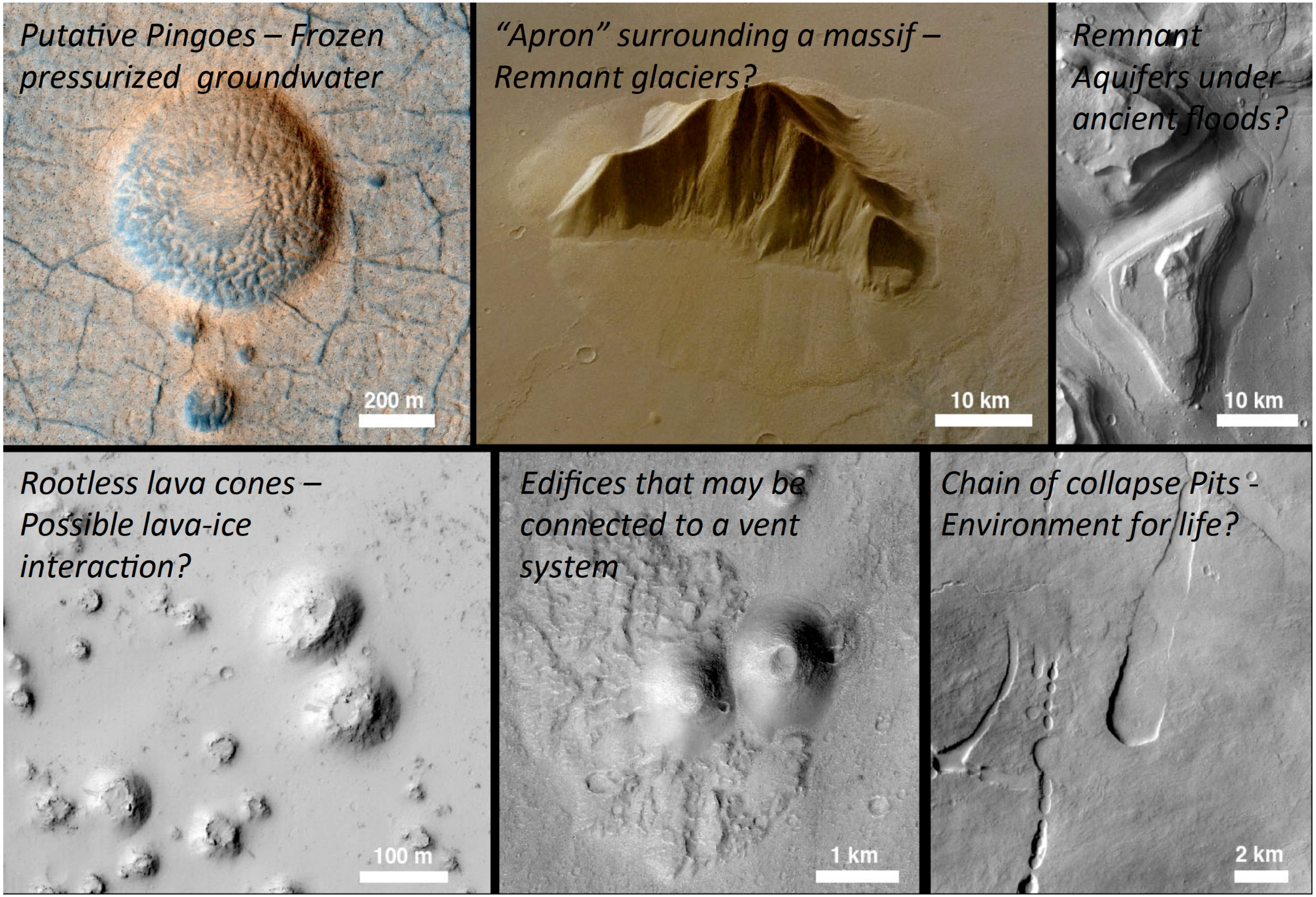
# Potential Geological Targets on Mars



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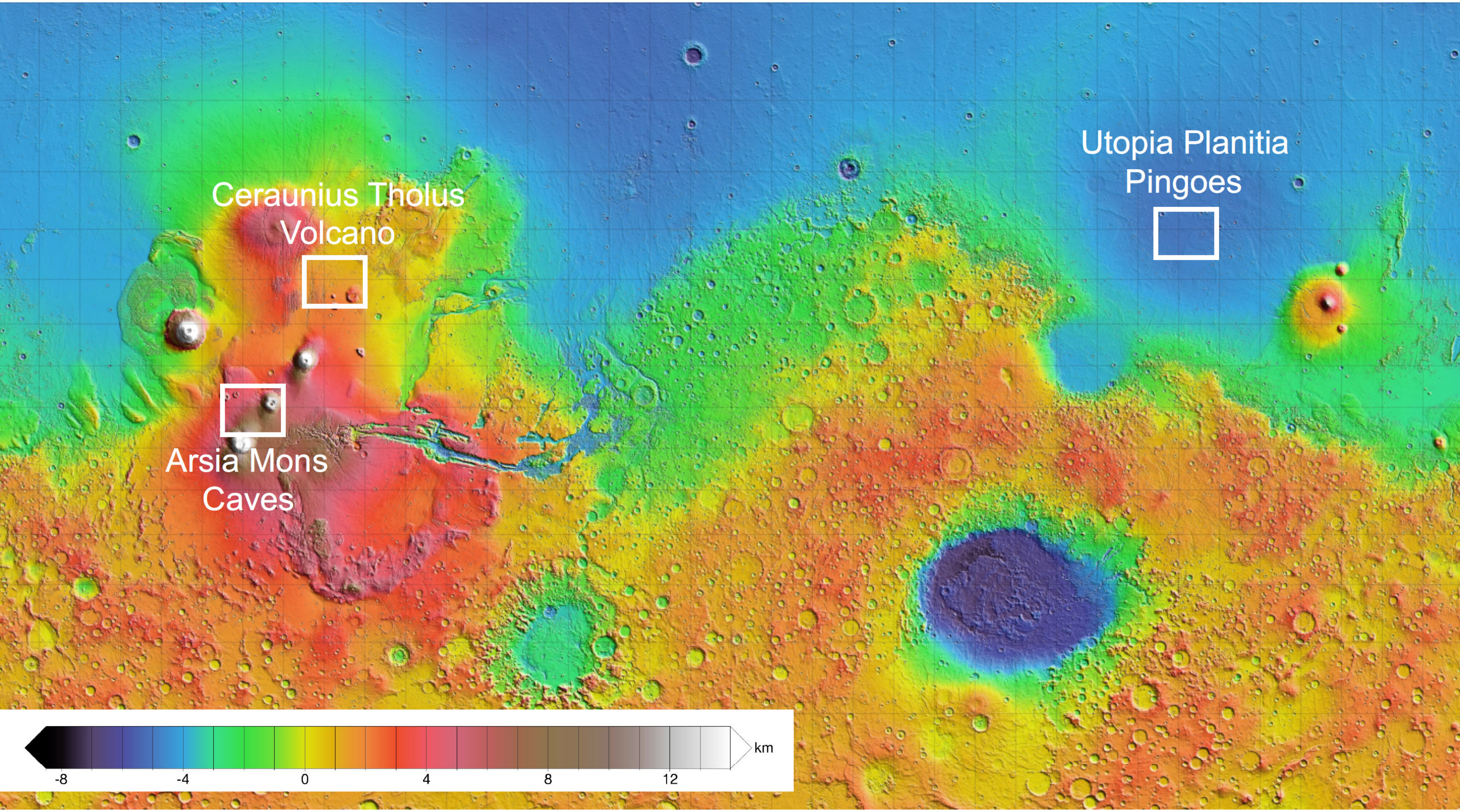

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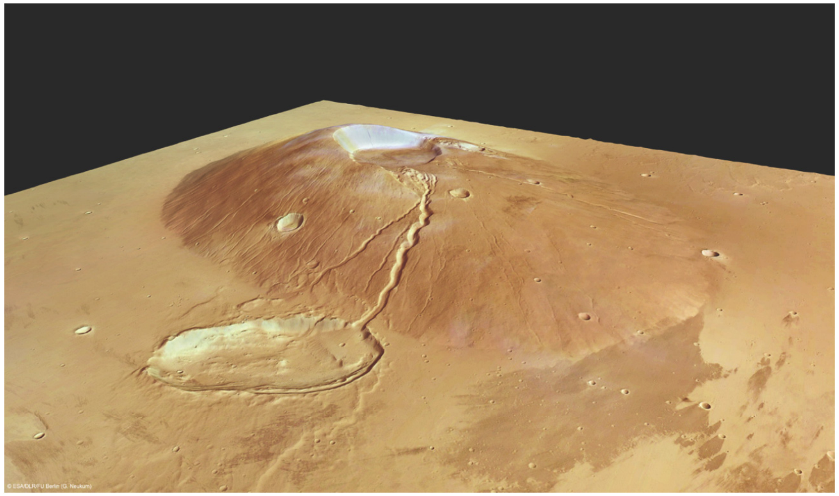
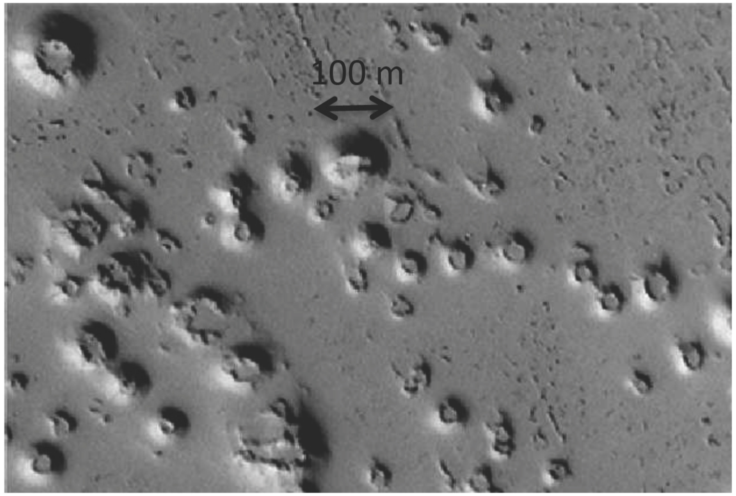
# Target 1 – Volcano and Small Cones

- Several regions on Mars contain lava flows with very sparse impact crater populations, implying ages of eruptive activity as young as a few million years.

Small cones, ice volcanoes, possibly due to lava vaporizing subsurface ice. Superheated steam punches through the cooling lava creating the surface structures.





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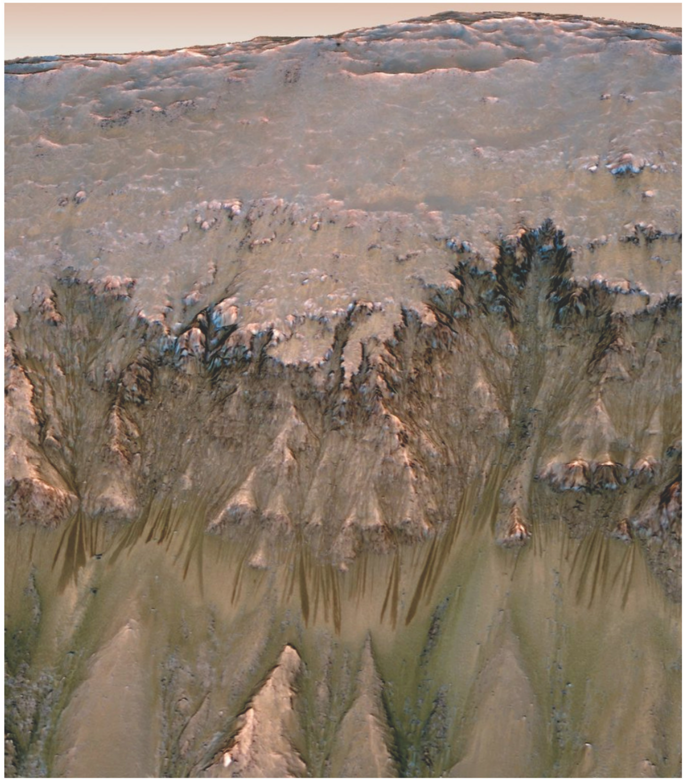
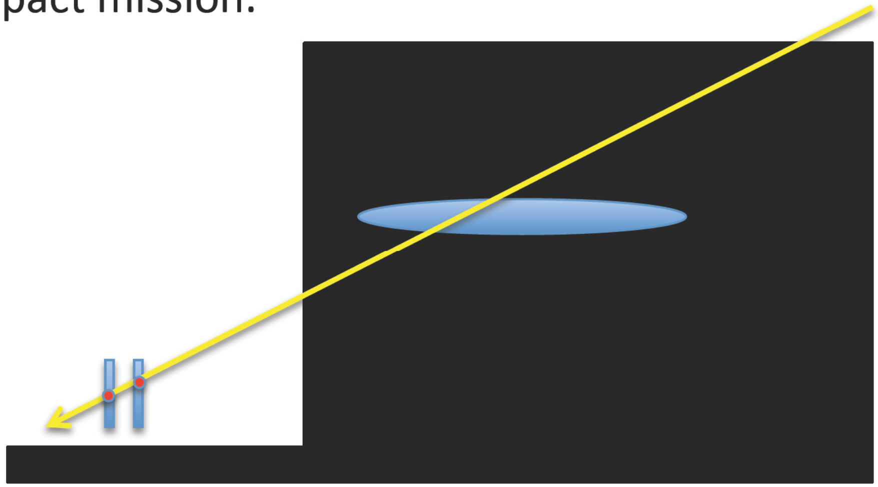
# Target 2 Mars Gullies

Oblique View of Warm Season Flows in Newton Crater



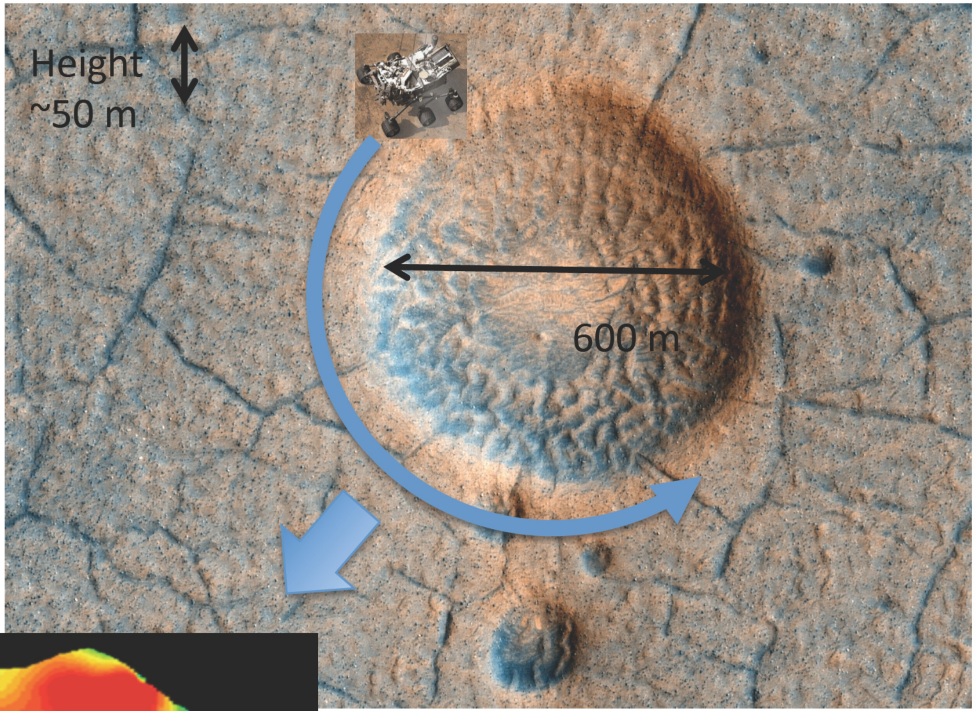
Recent MRO observations show flows that appear in spring and summer on a slope inside Mars' Newton crater. Sequences of observations recording the seasonal changes at this site and a few others with similar flows might be evidence of salty liquid water active on Mars today. If further study of the recurring dark flows supports evidence of brines, these could be the first known Martian locations with liquid water, and a prime candidate for an impact mission.

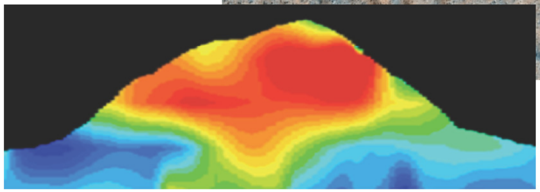


# Target 3 Pingoes

- Pingoes are small uplifts formed (on earth) by injection of pressurized groundwater beneath permafrost.

- Muon Tomography
  - Detect density variations inside the landform
  - Delineate ice body and overlying regolith
  - Address larger goal: What is hydrologic history of these areas?
  - Identify possible targets for ice sampling



Muon Tomography of lava dome at Usu volcano
International in Japan Workshop on High Energy Geophysics 2011

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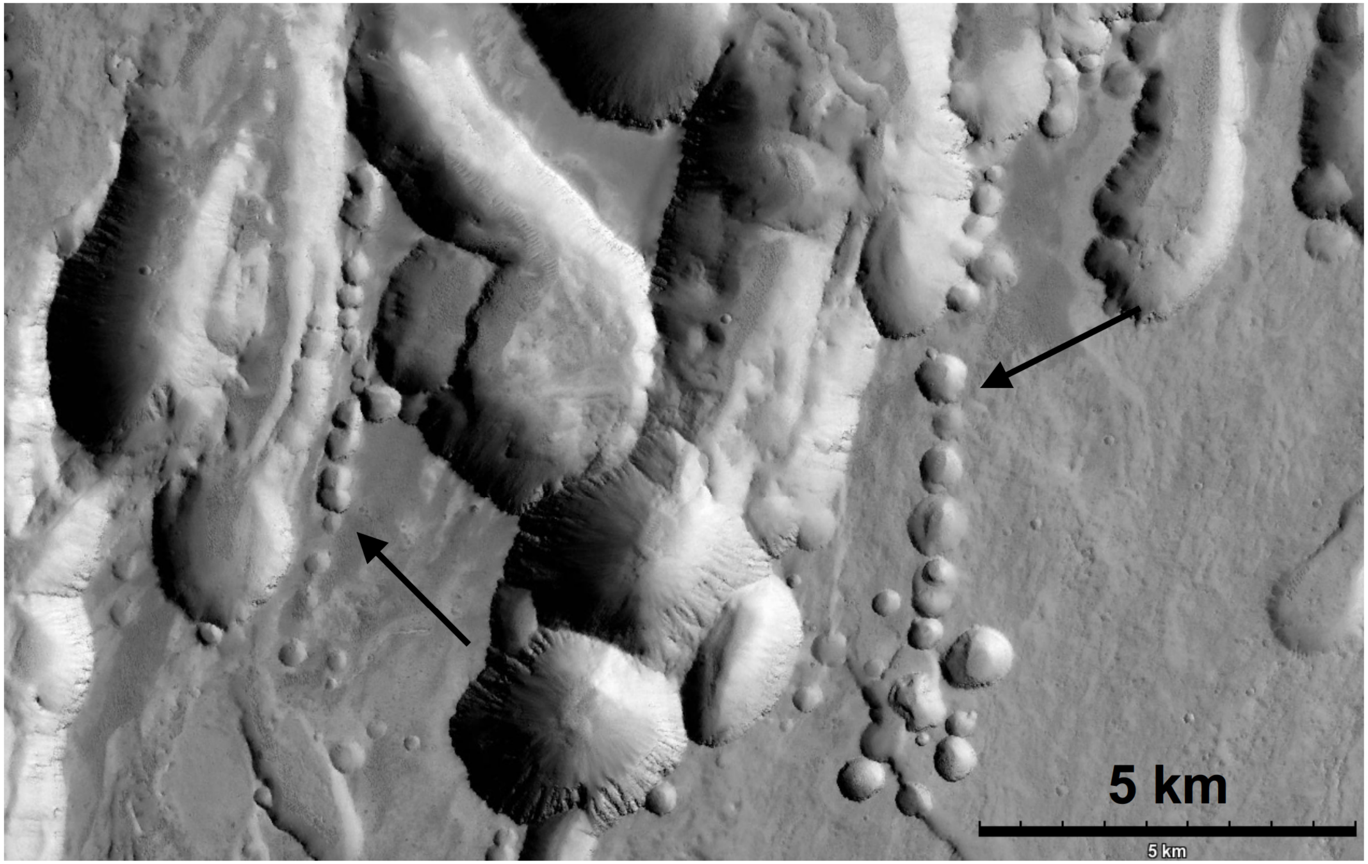
# Target 4 – Lava tubes and caves

- Chains of pits on large volcanoes indicate collapse of lava tubes. Partially collapsed tubes contain caves shielded from harsh radiation and extremes of temperature.



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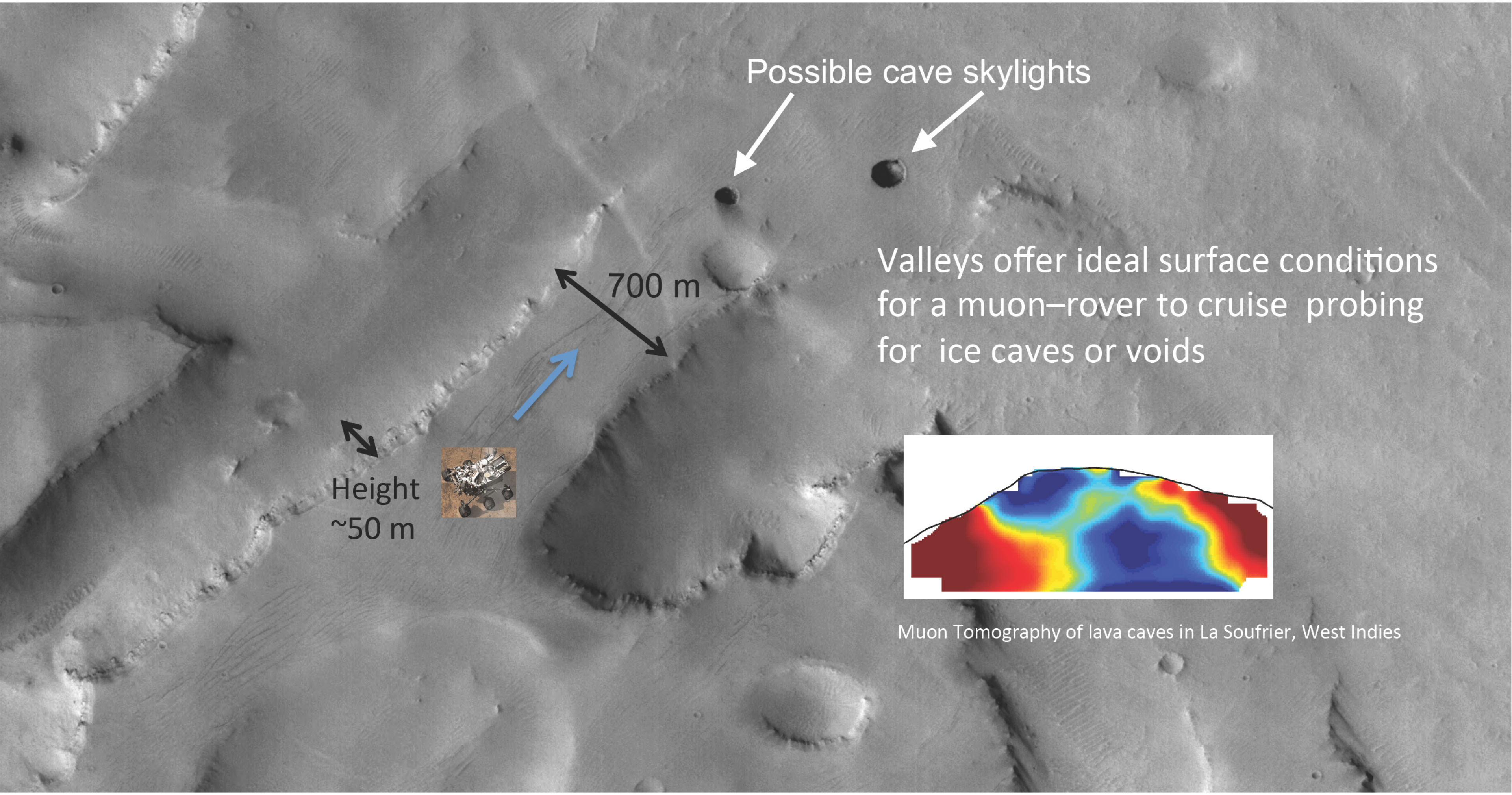


Arsia Mons - HiRiSE/U of Ariz/NASA

# Summary

- It has been demonstrated on Earth that a low power, passive muon detector can penetrate deep into geological structures up to several kilometers in size providing high density images of their interiors.

- Muon Tomography is an entirely new class of planetary instrumentation that is ideally suited to address key areas in Mars science, such as:
  - the search for life and habitable environments,
  - the distribution and state of water and ice, and
  - the level of geologic activity on Mars today.

and address a key priority of the decadal survey and MEPAG.

- *To detect deep and shallow subsurface habitable environments*

A mission that includes a muon detector could set the stage for a future mission to directly explore subsurface habitable environments Mars, as foreseen in the Planetary Science Decadal Survey